Energy Efficiency of Future Central and/or Linked Distributed Function Network Using Optical Technologies

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Abstract— **Recently cloud service and M2M or IoT service will become popular for different applications. So two different optical network architectures are proposed for creating future energy efficient network services. The first architecture is a centralized approach for higher energy efficiency; it uses a data center-centric optical aggregation network based on wavelength / time-slot multiplexing. All layer-3 or upper traffic are transferred through the simple metro / access optical aggregation network and switched in centralized scalable giant router at the data center. Total power consumption of the network can be reduced hundred fold compared to the existing Internet. The second is service mash-up by linked data through a network that uses broadband optical wire for the IoT era. All service contents, hardware, and also software programs are defined as service parts. Huge bandwidth optical wire interconnects some service parts and creates new mash-up services in the network. That creates deep network functionality in combination with network and processing functions. Network services are always moving like pendulum, so both two technologies can be applied future network service.**

Keywords— Photonic network; Access network; Energy efficient; Metro network; Future network; Data center; PLZT

I. INTRODUCTION

The Internet is the key infrastructure of daily life. Data traffic, which includes real-time traffic and routing traffic, now exceeds 15 Tbps [1]. Internet traffic consists of Peer-to-Peer (P2P) traffic such as file exchange, Voice over IP (VoIP), Video over IP, etc. or Client-to-Datacenter (C2D) traffic for server-client communication including Web access, content download, and data file download. [1].

The first problem is that the network structure of today's Internet does not suit for data center access traffic. Instead, we need the "data center centric" architecture [2]. The Internet is originally a flat structure network consisting of interconnected autonomous systems (ASs). It is scalable and plug-and-play and so suits changes in traffic demand. On the other hand, Internet of things (IoT) became highlighted. IoT involves adding a huge number of sensors, terminals and processing/server functions to the network. This paper expands the definition of IoT to call "Service Part (SP)". SP includes not only hardware but also contents data or software programs. IPv6 addresses are assigned to all SPs and SPs can interconnect with each other. This architecture suits distributed and linked data (Fig.1) [3]. For the data center centric architecture, we emphasize the technologies and background.

The dominant Internet service providers (ISPs) and content delivery network (CDN) providers are called the hyper-giants. The top 30 hyper-giants (Google, Yahoo, Amazon, Akamai, etc.) generate more than 30% of all Internet traffic [1]. Unfortunately, the worldwide power consumption of network devices has been increasing over 12% every year. In 2008, it was 25 GW, and in 2020 it will quadruple to reach 97 GW [4]. This is one of the most important problems.

Fiber to the home (FTTH) or passive optical network (PON) is a global major access network technology. The Long-Reach PON (LR-PON) is being researched to determine capital expenditure (CAPEX) and operational expenditure (OPEX) in access and metro network areas [5], [6] when accommodating large numbers of users in wide coverage areas. Figure 2(a) is increasing data center traffic and (b) is IoT number of devices. [7], [8]. It is clear that this trend will not be terminated in near future.

Given the above background, this paper proposes two network architectures; the Data Center Centric Architecture is used by optical aggregation network while the Distributed Linked service parts Network Architecture uses optical wire interconnects. The architecture provides wide bandwidth to a centralized data center having giant layer-3 (L3) routers through a wide optical time slot with WDM aggregation network. In other words, all user data is transferred to a centralized L3 router through the optical aggregation network transparently. The optical aggregation network supports huge number of subscribers aggregated by its combination of time slot switching and WDM. Therefore, each time slot flexibly supports various kinds of services, such as residential services, small data centers, business users, small office home office (SOHO) users, and mobile backhaul. Each time slot transfers data between the customer premises equipment (CPE) and the centralized giant L3-router transparently. Since the proposed network architecture has no electrical router functions, the optical aggregation network reduces the network power consumption dramatically compared to the current Internet [9], [10].

On the other hands, IoT such as sensor network is distributed components, but they are not able to centralize to the data center. So opposite way is the linked-data network as

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described as approach 2. For this, we have been proposing the service mash-up network named E[3]-DCN [11], [12]. All contents (picture, movie, sensor data, etc.), hardware (CPU, memory, storage, display, video camera, etc.), and software programs (game, application software, etc.) are defined as SPs. SPs are dynamically interconnected by optical wires to produce new mash-up services.

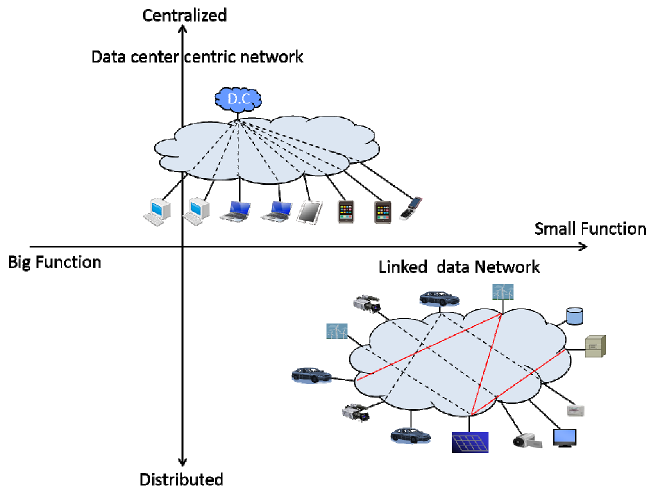

Fig. 1. Typical future network structure.

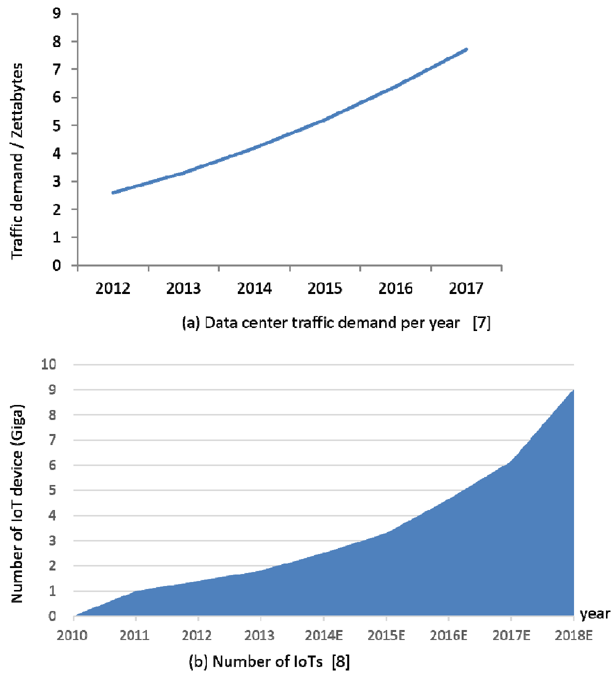

Fig. 2. Traffic demand and device number for both data center and IoT.

II. DATA CENTER CENTRIC ARCHITECTURE (APPROACH#1)

Major Internet application services, such as social network service (SNS) or YouTube, are migrating to C2D service. This migration to C2D service indicates that the whole network structure needs to be restructured, not just the access network. Fig. 3 (a) shows the basic Internet network structure; multiple autonomous systems (ASs) are interconnected.

This network structure is easy to expand to meet traffic demand, and scale to meet greater numbers of Internet users. Plug-and-play is also possible for ASs/routers/hosts. However, the structure does not suit C2D traffic. This is because of traffic from users toward the data center of the hyper-giants is more than 40% of all Internet traffic. Our optical aggregation network architecture is the solution as shown in Fig. 3 (b).The network consists of a simple transparent aggregation network realized by optical circuit switches, and wavelength-multiplexer/de-multiplexers, and a massive centralized power-scalable L3-router in the data center. In the proposed architecture, the metro / access optical aggregation network has a simple multiplexing function and so is very energy efficient.

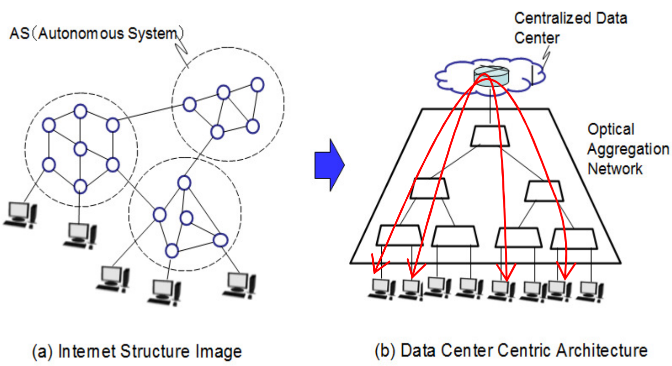

Fig. 3. Future data center-centric network architecture.

III. DISTRIBUTED LINKED NETWORK ARCHITECTURE (APPROACH#2)

Our other proposal is the distributed linked network architecture. In the future network, billions of sensors, content processing functions, and also terminals, will be assigned IPv6 addresses and widely dispersed. The optical Internet provides flexible and systematic connections among them with optical wire.

In the distributed linked network architecture, contents, hardware, programs, and functions are defined as "Service Parts" and are interconnected by optical wires. An optical wire provides a logical connection or path to an SP that offers huge bandwidth, security, and minimal delay. The linked data network exchanges meta-data and SPs are connected by extract key matching such as location, function, capability, etc. The combination of network functions, such as named data search, linked data matching, and optical wire, and SPs creates new mash-up services. Figure 4 shows an example. The network provides 3 functions (A, B, and C). The contents are transferred from source to destination via A, B, and C. Functions A, B, and C customize the input content. The source SP provides an ISO image data, function A SP provides DVD player software and MPEG2 data output, function B SP provides video enhancement, and function C SP provides digital rights

management (DRM), finally, a DRM protected enhanced video image is generated as a customized content. This architecture allows the virtual creation of highly functional networks. This concept was proposed as uGrid (ubiquitous grid network environment) [13-15].

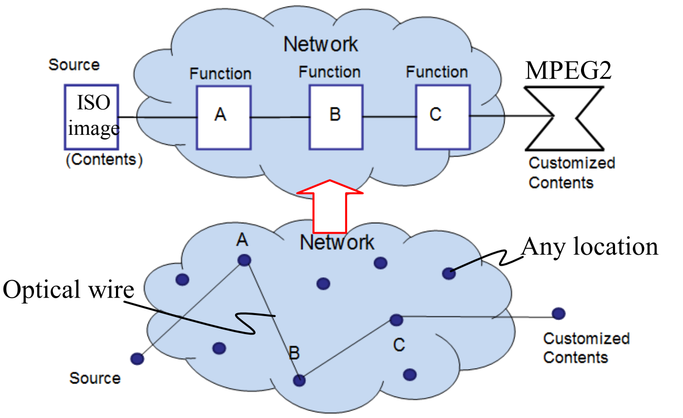

Fig. 4. An example of a mash-up service on the distributed linked network architecture.

IV. Approach#1: Metro/Access Optical Aggregation Network

The proposed optical aggregation network can accommodate a large number of users and enable long distance transmission between users to central data centers; it creates many kinds of services provided by only at the data centers. Data are transparently transferred from users through the optical aggregation network. The optical aggregation network decreases power consumption by reducing the number of large power consumption electrical devices. The average number of routing hops in the conventional Internet is nearly twelve [16], whereas the proposed one has only 1 hop at the data center. This router is power scalable to traffic demands, i.e. active switching capacity is proportional to the amount of traffic, and it offers huge statistical multiplexing gain. This architecture has an advantage of high energy efficiency. According to [16] and [17], the relationship between consumption and throughput. Equation (1)

$$P = A \cdot C^{2/3}, \quad (1)$$

Where P [watt] is router power consumption, C is router throughput [Mbps], and A [watt $\cdot$ Mbps$^{-2/3}$] is a constant. The value of A is 1.0 in Eq. (1).

This equation indicates that increasing electrical router throughput improves the energy efficiency; power consumption per-bit decreases as router throughput increases. Accordingly, the proposed architecture utilizes extremely large capacity electrical routers only at central data center.

We introduce a second important background issue; the power consumption characteristic of switches. References [17] and [18] describe power consumption issues in future high-capacity switching systems, and examine different architecture implementations both all-electronic and all-optical.

This paper shows that optical-switched node significantly reduces the power consumption of the switching function from electrical router. Of course this comparison is not fare, because packet switch and circuit switch have different switching function. However, this graph shows that circuit switching is higher energy efficient than packet switching. So this is because electrical L3 functions are extremely complicated compared to the optical circuit switched functions under different functions but some switching throughput. MEMS-based optical circuit switched nodes without wavelength-converters can reduce the power consumption 500 times compared to the electric packet switched node. Therefore, we adopt optical circuit switching to realize the metro / access optical aggregation network [9], [10], [19].

We used very high-speed (less than 10ns switching) (Pb,La)(Zr,Ti)O3 (PLZT) optical switches [20], [21] to implement a prototype system, see Figure 5. This prototype includes a newly proposed automatic ranging function [22] that can handle more than 128 optical network units (ONUs) with 40 km length links, that is longer than the conventional limit of 32 ONUs at 20 km [23].

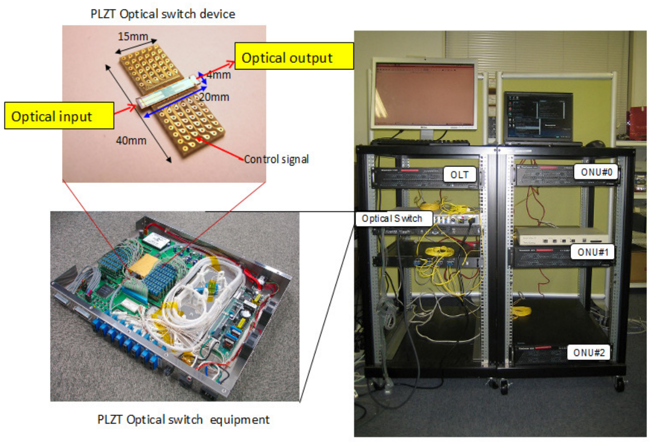

Fig. 5. Prototype of optical slot aggregation switch network.

PLZT switches offer extremely high-speed switching (nano-second order), and can greatly decrease the optical power loss compared to the optical splitters used in current PON systems. In case of upstream data, the optical aggregation network uses simple data multiplexing function. For downstream data, pre-fixed slot distribution switching with source routing is applied. Because there is no complicated header processing or store-and-forward queues in the optical aggregation network, it is a simple and buffer-less network. These features greatly enhance energy savings. Details are discussed in [24].

To feed the data center the proposed metro / access optical aggregation network is realized by optical WDM/slot aggregation technologies. The traffic data are aggregated and transferred through the optical lower layer. In other words, this simple optical aggregation network realizes a one hop L3 network. Figure 6 shows the power consumption of an IP

network implemented by the current Internet and by the proposed metro / access optical aggregation network. The proposed network architecture reduces the power consumption to 20 times compare to the current Internet.

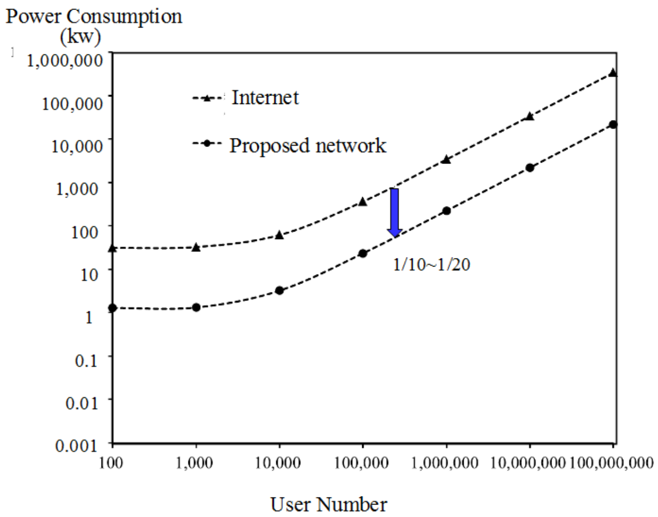

Fig. 6. Power consumption reduction by the proposed architecture.

V. Approach#2: Optical Wired Mash-up Service Network (E^3-DCN)

uGrid defines not only hardware such as central processing units (CPUs), graphics processing units (GPUs), memories, storages, personal computer peripherals, displays, video cameras, game machines, and smart phones but also software programs as "Service Parts (SPs)". This is called "Everything as a Service Part". Linking SPs by optical wires creates new mash-up services. SP combinations can be formed without regard to location (and owner if possible) to create an optical wired network mash-up service without any bandwidth or delay restriction. In other words, any SP (if open access is possible) can be used by any user in a dynamic manner.

The uGrid concept can be applied to yield information-centric networking (ICN) [25] and the content-centric network (CCN) [26]. CCN is one of the most promising technological targets of the new generation network (NwGN) in Japan or the Future Networks in EU/USA. CCN mainly transfers large content sets as transport units in the service network layer. CCN can act as a content delivery network, while uGrid can acts as a content generating network. The E^3-DCN concept [11], [12] unites CCN and uGrid in the network virtualization environment and applies an energy aware routing method to both networks. Two energy-aware routing strategies are applicable to E^3-DCN as show in Fig.7.

E^3-DCN and uGrid provide an in-network processing feature. This means that the end-to-end service path is not transparent and data conversion within the network is possible. The network provides not only transportation but also the content creation service called data generation overlay network. As a result, future energy efficient mash-up services allow users to dispense with the need to own hardware or even complicated software functions; the network provides the user with the desired customized service.

In the E^3-DCN, overlay network can be considers real physical network performance such as delay, energy consumption or bandwidth through network application programming interface (API). This architecture is now going to try on the JGX-X, which is Japanese future internet testbed.

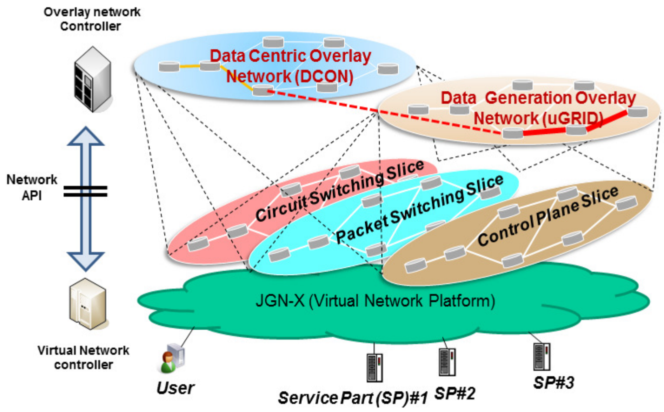

Fig. 7. E^3-DCN for expanding uGrid concept on the virtual JGN-X testbed network.

VI. Conclusion

This paper proposed two attractive future optical network architectures. One is the Data Center Centric Architecture realized by a new optical aggregation network for the next generation network. The architecture consists of giant L3 routers and optical aggregation network. Internet traffic data are transferred to data centers, within which giant L3 routers switch the traffic. The current Internet creates a large number of hops but the proposed network architecture needs only one. The optical aggregation network can realize simple metro/ access networks without complicated L3 interconnection functions. This architecture reduces power consumption. The proposed optical aggregation network dramatically reduces the network power consumption up to 20 times compared to the current Internet.

The second proposed architecture, the service mash-up network named uGrid, uses dynamic optical wires. These huge bandwidth dynamic optical interconnections can create location-free mash-up services. The service part in the uGrid network encompasses not only hardware components but also software. This idea can be extended to yield the virtual data creating network named E^3-DCN. Both the aggregation network and the mash-up service network can be applied to establish future optical network services.

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